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The use of sharp cut-off vestigial sideband filters at television transmitting stations

No. 1969/4

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

THE USE OF SHARP CUT-OFF VESTIGIAL SIDEBAND FILTERS AT TELEVISION TRANSMITTING STATIONS

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SUMMARY

An amplitude and group-delay characteristic of the special vestigial sideband filters that may be required at u.h.f. stations working in a channel adjacent to a radio astronomy band is considered, and the effect on transient response assessed. The group-delay errors of the filter, which is assumed to be at the transmitter output terminal, can be satisfactorily corrected by simple all-pass networks in the video stage before modulation. This correction may tend to produce overshoots on sharp transients of the modulation waveform within the transmitter; this effect could be troublesome if the signal handling capabilities of the transmitter are limited, though in practice, the amount of overshoot is not likely to be excessive.

1. INTRODUCTION

Wharton[1] has discussed the specification of the radiated spectrum of 625-line vestigial sideband broadcast transmissions, and proposed that the resulting K-rating of a 2T sine-squared pulse, (or simply, 2T pulse) when using an ideal phase-corrected receiver with an envelope detector, should not exceed 1·5%.

In the case of certain transmitters working in u.h.f. Channel 39, stringent requirements of the adjoining radio astronomy band demand a more rapid cut-off of the vestige response than that previously specified. Requirements to protect users of adjacent frequencies may also arise in the case of Channel 21. If minimum phase-shift filters are used this will inevitably increase the group-delay variations in the vision sidebands, and will cause a deterioration in the K-rating. In principle, group-delay correction circuits can be used to improve the K-rating, but there are practical and economic limits to the amount of correction which can be obtained. The present work was carried out to find if a satisfactory K-rating can be obtained without excessive circuit complexity, provided other sources of group-delay errors are comparatively small.

Consideration is also given to the amount of overshoot on transients which may arise in some of the transmitter circuits following the application of delay correction.

When calculating the r.f. responses, account is taken of the effect of asymmetrical sidebands on the envelope (the 'quadrature distortion').

2. RECEIVER CHARACTERISTICS

In defining an acceptable specification for the filter characteristic, it is necessary to specify the receiver characteristic. For this purpose, it is convenient to assume that the receiver is ideal, in the sense that it has a linear phase response, and that it has an amplitude response (on a relative voltage scale) rising linearly from zero at 1·25 MHz below the vision carrier to unity at 1·25 MHz above the carrier, and thereafter remaining at unity. This is shown in Fig. 1. In domestic receivers there is a tendency for the slope through the carrier to be steeper,[2] and this will reduce the effect of the transmitted vestige group-delay errors. The receiver will, however, be more prone to delay errors in its own circuits. The i.f. characteristic of the domestic receiver used in some of the following tests is shown in Fig. 2.

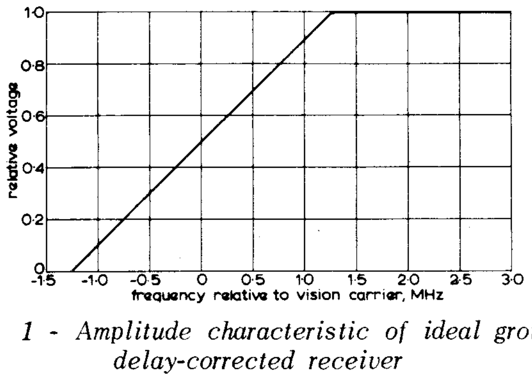

Fig. 1 - Amplitude characteristic of ideal group-delay-corrected receiver

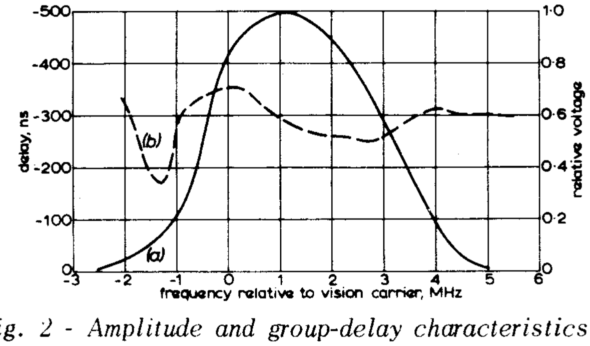

Fig. 2 - Amplitude and group-delay characteristics of domestic receiver
(*a*) Amplitude (*b*) Group-delay

3. THE VESTIGIAL SIDEBAND FILTER CHARACTERISTICS

The exact amplitude characteristic required of the filter depends on the power and siting of the transmitter and upon the level of permissible interference to the adjacent channel. Fig. 3 shows a specification template for a particular case; in this diagram the frequencies are given relative to the vision carrier. There is very little flexibility permitted in the choice of shape of the amplitude characteristic in the region of the vision carrier. It seems that a nearly maximally-flat amplitude characteristic is demanded, except for the region of high attenuation below the vision carrier. Below 1·5 MHz, there is a fairly wide tolerance on the shape of the characteristic.

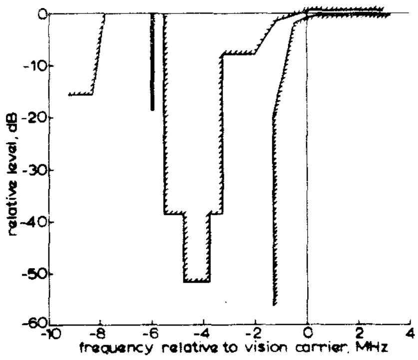

Fig. 3 - Example of v.s.b. specification template

It would appear from Fig. 3 that the specification might best be met by a combination of a maximally-flat bandpass filter, in series with some notch filters to obtain adequate rejection at the deep minima. For simplicity, it is assumed that these notch filters are isolated from each other, and that their delays (in ns) and attenuations (in dB) are additive. The practical embodiment of such an arrangement is outside the scope of this report, but it is supposed that any practical filter which has a similar amplitude characteristic will also have a similar group-delay characteristic, and will, therefore, require a similar delay correction.

The relevant amplitude and group-delay characteristics of such filters are defined in the Appendix, Sections 9.1 and 9.2.

Some trial calculations* indicated that the most promising arrangement would be an eighth-order maximally-flat bandpass filter with a bandwidth of $\pm 4{\cdot}25$ MHz, centred on $+2{\cdot}75$ MHz relative to the vision carrier frequency, in series with three notch filters centred on $-4{\cdot}65$ MHz, $-4{\cdot}25$ MHz, and $-3{\cdot}85$ MHz. The resultant characteristics are shown in Fig. 4, superimposed on the template of Fig. 3. A good fit to the amplitude specification is obtained, apart from some transgression of the template in the region of $-3{\cdot}25$ MHz, but the corresponding group-delay variation near the vision carrier is rather large.

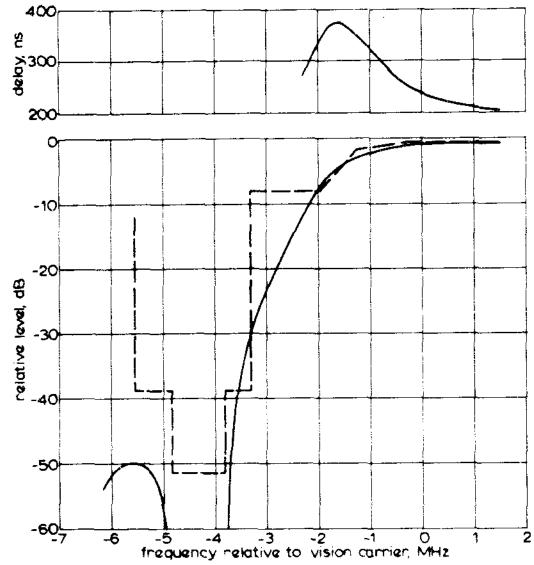

Fig. 1 - Amplitude and group-delay characteristics of v.s.b. filter

4. 2T PULSE RESPONSE

To find the effect of the filter discussed in Section 3, the 2T pulse responses from an ideal receiver (see Fig. 1) and a domestic receiver (see Fig. 2) were computed, together with the corresponding K-ratings, for the following cases:

(a) Assuming a perfect double-sideband transmission with uniform group-delay.

(b) Assuming a transmitted amplitude characteristic as given in Fig. 4, with uniform group delay, i.e. assuming the use of a transmitter filter with perfect group-delay correction at radio frequency.

(c) Assuming transmitted amplitude and group-delay characteristics as given in Fig. 4, the delay being constant at frequencies more than 2 MHz above the carrier frequency; this implies correction for group-delay errors at the higher video frequencies, such as may be provided as part of a standard installation.

The results of these calculations are given in Table 1.

TABLE 1

K-Ratings for Ideal and Domestic Receivers
K-rating, %

Case	Ideal Receiver		Domestic Receiver	
	K_{2T}	$K_{P/B}$	K_{2T}	$K_{P/B}$
a	0·9	0·3	7·2	15·8
b	1·3	0·9	7·0	15·9
c	2·7	0·8	9·0	17·5

* This preliminary investigation was carried out by M.G. Croll.

The relatively small change in the performance of the domestic receiver in case (b), compared with its response when fed with an unimpaired signal, tends to confirm that, in assessing the effect of the transmitter vestigial sideband (v.s.b.) filter, attention can be concentrated on the results obtained from an ideal receiver, and that if the filter causes only a small effect on the response of this receiver, the effect on domestic receivers will be negligible.

The response of the ideal receiver indicates that the asymmetrical amplitude characteristic of the filter causes some impairment of performance, but the group-delay characteristic has most effect.

5. GROUP-DELAY CORRECTION AT VIDEO FREQUENCY

In principle, it is better to apply group-delay correction to the modulated radio-frequency (r.f.) signal, but it is usually more convenient and economic to carry out the correction in the video-frequency (v.f.) circuits before modulation. Perfect correction of both upper and lower sidebands, which is necessary if it is to be effective for a variety of possible amplitude-response characteristics in the receiver, cannot be obtained by the latter method unless the r.f. delay characteristic to be corrected is symmetrical about the vision carrier. However, it is possible to obtain a useful partial correction at v.f.

Calculations were carried out for a simple all-pass phase equalizer, having a group-delay characteristic as defined in the Appendix, Section 9.3. Because delay correction introduced at v.f. is equivalent to an r.f. correction which is symmetrical about the vision carrier, it is inevitable that, for the delay curve given in Fig. 4, the correction required for the upper sideband acts in such a way as to increase the errors in the lower sideband. The effects of these errors are, however, reduced by the attenuation of the vestige in the receiver. Therefore, in deciding upon suitable parameters for the video delay corrector, attention was directed to produce a nearly flat upper-sideband delay curve.

Choosing design parameters of $\omega_0/2\pi = 2{\cdot}5$ MHz, and $M = 0{\cdot}35$ (see Appendix, Section 9.3), a delay correction curve, referred to the r.f. circuits, was obtained as shown in Fig. 5(*a*). Also shown is the delay curve of the v.s.b. filter (*b*) and the resultant overall characteristic (*c*) including the effect of the video delay correction. In all these curves the delay above 2 MHz is assumed to be constant. In practice there may be delay variations in that region, but this is a separate problem, which will be ignored at present.

The 2T pulse response from an ideal receiver was

$$K_{2T} = 1{\cdot}5\% \;:\; K_{P/B} = 0{\cdot}09\%$$

Comparing this with the corresponding value for case (c) in Table 1, it is seen that a considerable improvement has been achieved.

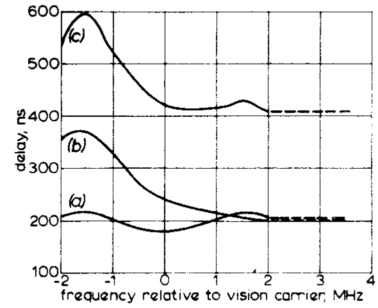

Fig. 5 - Group-delay characteristics

(*a*) Video corrector (*b*) Special v.s.b. filter (*c*) Overall

6. TRANSIENT OVERSHOOTS

6.1. Group-delay Correction at Video Frequency

While in principle group-delay correction can be applied in the v.f. circuits before modulation, it must be remembered that such correction may introduce an overshoot on sharp transients which could have an undesirable effect in subsequent stages of the transmitter, especially on colour transmissions. In particular, excessive overshoot on positive-going picture transients in the modulator may cause the carrier to swing towards zero at times. Also, an overshoot on the leading edge of the synchronizing pulse may be limited by non-linearity in the klystron output stage. It is not easy to predict the subjective importance of these effects, but it is useful to calculate the approximate magnitude of the transients which may occur.

As a starting point, the responses of a rectangular and a 2T pulse were computed for the video group-delay characteristic mentioned in Section 5. These waveforms apply to the video input to the modulator or to the envelope of a double-sideband modulated signal. The group-delay characteristic (referred to the r.f. circuits) is shown in Fig. 5 (curve (*a*)). The amplitude characteristic was assumed to be flat from d.c. (or the vision carrier frequency) to 5·5 MHz, and zero thereafter. The results are shown in Figs. 6 and 7. It is seen that the overshoot is not excessive, bearing in mind that in the case of the unit step, a 9% overshoot occurs even in a perfectly phase-corrected filter.

So far, consideration has been confined to delay variations caused by the v.s.b. filter. In practice, there may be other sources of delay errors, and on existing installations a certain amount of video phase correction is provided. It is, therefore, pertinent to consider the effects of such correction. Fig. 8 curve (*a*) shows a delay correction curve, which can be obtained in an actual transmitter, and although it does not necessarily represent the

normal working conditions, it is thought to be fairly typical. The corresponding responses to rectangular and 2T pulses are shown in Figs. 9 and 10 respectively (curves (*a*)), and it is seen that the overshoot is quite small.

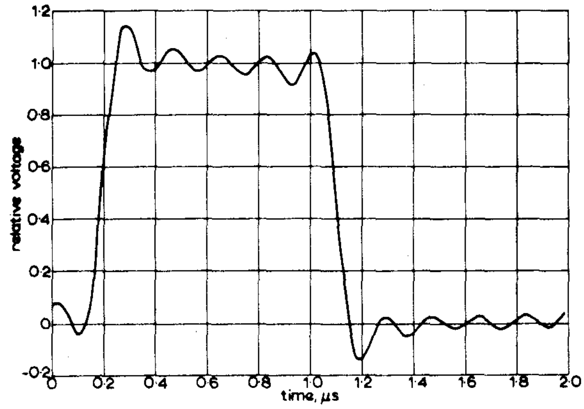

Fig. 6 - Rectangular pulse response of video all-pass delay corrector

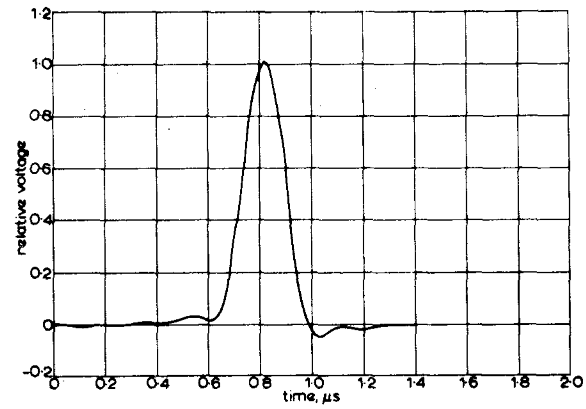

Fig. 7 - 2T pulse response of video all-pass delay corrector

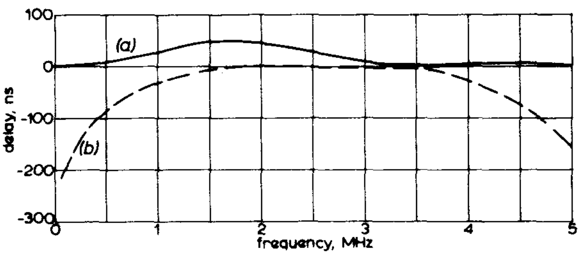

Fig. 8 - Possible characteristics of practical group-delay corrector

(*a*) Typical example (*b*) Somewhat extreme example

If circumstances demanded a much larger degree of correction (say a variation of 200 ns, as shown in curve (*b*) of Fig. 8, a greater degree of overshoot could occur (see curves (*b*) in Figs. 9 and 10). This overshoot may result in distortion caused by non-linearities at the extremes of the transfer characteristic, and the power handling capacity of the transmitter may consequently have to be reduced. Although it is believed that such large amounts of correction will not be required in practice, care must be taken to allow for the effects of corrections involved in the basic transmitter design as well as corrections for additional v.s.b. filtering.

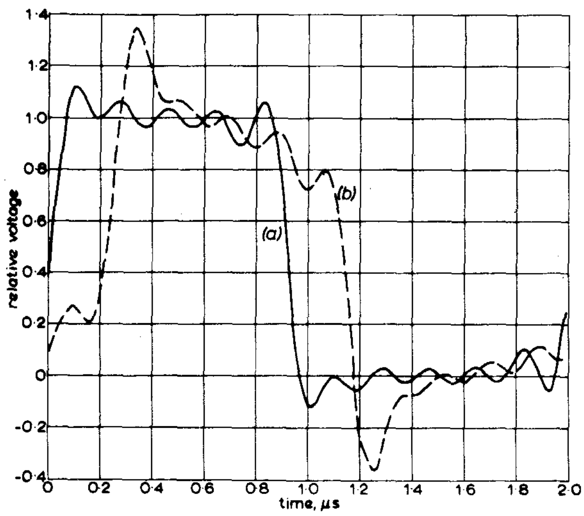

Fig. 9 - Rectangular pulse response of practical group-delay corrector

(*a*) corresponding to Fig. 8(*a*)
(*b*) corresponding to Fig. 8(*b*)

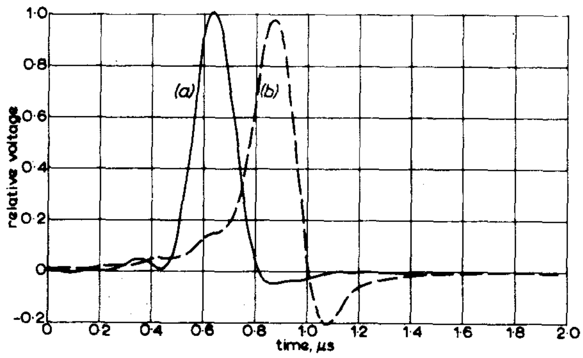

Fig. 10 - 2T pulse response of practical group-delay corrector

(*a*) corresponding to Fig. 8(*a*)
(*b*) corresponding to Fig. 8(*b*)

6.2. Group-delay Correction at Radio Frequency

If delay correction is carried out in the r.f. circuits, the problems arising are somewhat different, because different amounts of correction may be introduced for the upper and the lower sidebands, and in this case the resultant modulated envelope will not have the same form as when the correction is carried out in the v.f. circuits.

The envelope of a rectangular pulse between carrier level limits of 20% and 77% was computed for the group-delay characteristic shown in Fig. 11; the amplitude characteristic is assumed to be flat to ± 5·5 MHz. This delay curve has the form of the inverse of an estimated characteristic of a sharp cut-off v.s.b. filter similar to that shown in

Fig. 4, but having a somewhat greater group-delay variation. It therefore represents a fairly stringent example of the type of correction curve at which one might aim in a practical case. The envelope obtained is shown in Fig. 12; it is seen that the overshoot is not excessive.

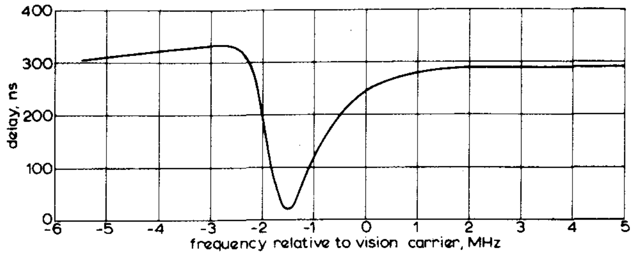

Fig. 11 - Possible characteristic of all-pass r.f. group-delay corrector

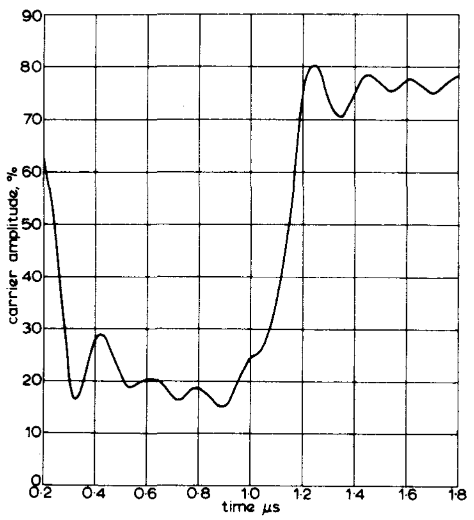

Fig. 12 - Rectangular pulse response corresponding to characteristic of Fig. 11

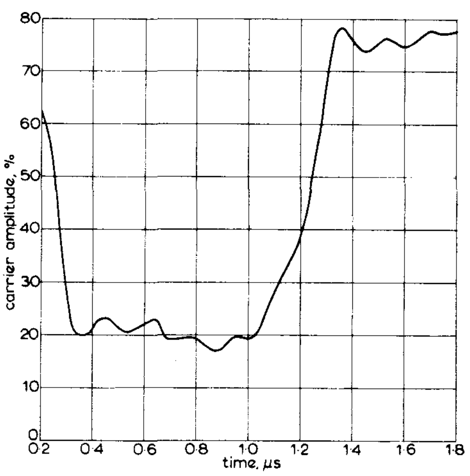

Fig. 13 - Rectangular pulse response corresponding to delay characteristic of Fig. 11, but with normal v.s.b. amplitude characteristic

In a practical case, the delay correction may be introduced at a point where the lower sideband is restricted in bandwidth, and in this case it is expected that the overshoot of the envelope would be somewhat less, because the total high-frequency power is reduced in comparison with the low-frequency power. This is exemplified in Fig. 13, which shows the envelope for the same delay characteristic as applied to Fig. 12, but with the lower sideband restricted in amplitude according to the normal transmitter vestigial sideband characteristic.

7. CONCLUSIONS

Although only a limited number of examples has been considered, the following conclusions may be stated:

(i) At stations working in a channel adjacent to a radio astronomy band, the sharp rate of cut-off of the vestigial sideband filter will, if minimum-phase-shift networks are used, result in an unacceptably high K-rating, unless the group-delay variations are at least partially corrected.

(ii) Provided that the only delay variations are those due to a minimum phase-shift v.s.b. filter, a satisfactory K-rating can be achieved by means of simple group-delay correction circuits in the video frequency stages before modulation.

(iii) If the delay correction is applied in the video stages, as mentioned in (ii), care must be taken to verify that the overshoot on transients in the modulator and succeeding stages is not excessive. This problem should not be severe for the amount of correction required for minimum-phase-shift v.s.b. filters alone. Particular transmitters may, however, incorporate additional correction for other purposes, and this may lead to greater difficulty.

(iv) It is preferable from the point of view of reducing overshoot in the transmitter to introduce delay correction in the r.f. (or i.f.) circuits after modulation. Lower overshoot will occur if the correction is applied at a point where the lower sideband is restricted in bandwidth.

In a practical case, group-delay errors may arise which exceed the minimum errors discussed in this report. In order to evaluate the problem more fully, calculations should be made based on the performance of an actual transmitter, in terms of amplitude and group-delay characteristics, and the degree and type of non-linearity at various stages in the transmitter.

Another question which has not been considered is that of amplitude-dependent phase variations. in order to investigate this aspect, details of the circuits involved would be required.

8. REFERENCES

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2. Pulse response of domestic u.h.f. television receivers and its relation to the amplitude and group-delay characteristics. BBC Research Department Report No. RA-27, Serial No. 1968/57.
3. ORCHARD, H.J., 1960. The phase and envelope delay of Butterworth and Tchebycheff filters. *I.R.E. Trans. Circuit Theory,* 1960, **CT-7**, 2, pp. 180–181.

9. *APPENDIX*

9.1. Characteristics of Maximally-flat Band-pass Filter

It is assumed that the characteristics of the band-pass filter can be obtained directly from those of the low-pass prototype. This assumption is justified when the fractional bandwidth of the band-pass filter is small, as in the case being considered. For the low-pass filter,

Let $\omega/2\pi$ = frequency

$\omega_c/2\pi$ = cut-off frequency,

n = order of the filter,

A = output amplitude, in relative volts,

and D = group-delay, in units consistent with ω_c,

Then

$$A = \frac{1}{\sqrt{[1 + (\omega/\omega_c)^{2n}]}}$$

and

$$D = \frac{\displaystyle\sum_{m=1}^{m=n} \frac{(\omega/\omega_c)^{2m-2}}{\sin[(2m-1)\pi/2n]}}{1 + (\omega/\omega_c)^{2n}} \qquad \text{(ref. 3)}$$

9.2. Characteristics of Notch Filter

Let $\omega/2\pi$ = frequency

$\omega_r/2\pi$ = resonant frequency,

C = a constant, depending on the L/C ratio,

$$x = \frac{C}{2}\,\frac{\omega - \omega_r}{\omega_r}$$

A = output amplitude, in relative volts,

D = group-delay, in units consistent with ω_r,

Then, to a good approximation,

$$A = \frac{2x}{\sqrt{(1 + 4x^2)}}$$

and

$$D = \frac{C}{\omega_0}\,\frac{1}{1 + (C/\omega_0)^2(\omega - \omega_0)^2}$$

9.3. Characteristics of Single-Section All-pass Group-delay Corrector

Let $\omega/2\pi$ = frequency,

$\omega_1/2\pi$ = a reference frequency,

M = a design constant,

D = group-delay, in units consistent with ω_1,

Then,

$$D = \frac{\dfrac{4M}{\omega_1}(1 + [\omega/\omega_1]^2)}{[\omega/\omega_1]^2 + 4M^2(1 - [\omega/\omega_1]^2)^2}$$

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